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SIMPLIFIED THERMAL TRANSIENT TEST FOR ELECTRO EXPLOSIVE DEVICES

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Rosenthal	
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Testing	
Detonator	

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

A simplified thermal transient test system for bridgewire-initiated electro explosive devices is described. The method used is that developed by Rosenthal. An automated data recording system and computer analysis of results are included.

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INTRODUCTION

The Rosenthal thermal transient test for bridgewire-type electro explosive devices (EED) is used for nondestructive testing of the interface between the wire and the explosive (ref 1).

The thermal transient test is based on the application of a current to heat the bridgewire, and then monitoring the change in resistance of the wire as it heats to determine its temperature response. For this reason, only bridgewires with a measurable thermal coefficient of resistance can be tested. This work describes a simplified testing system and an improved method of data analysis.

THEORETICAL BACKGROUND

According to Rosenthal's differential equation for bridgewire temperature rise as a lumped thermal system (ref 1), bridgewire heat balance is:

$$C_p \frac{d\phi}{dt} + \gamma\phi = p(t) = I^2 R_o (1+\alpha\phi) \tag{1}$$

where

C_p = heat capacity, watt-second/degree
ϕ = temperature increase, °C
t = time, second
γ = heat loss factor (linear thermal conductance term), watt/degree
p = power input, watts
I = excitation current, amps
R_o = initial resistance, ohms
α = temperature coefficient of resistivity of bridgewire

The solution for equation 1 is:

$$\phi(t) = \frac{I^2 R_o [1-\exp(-\frac{\gamma' t}{C_p})]}{\gamma'} \tag{2}$$

where $\gamma' = \gamma - I^2 R_o \alpha$

The voltage drop $v(t)$ across the bridgewire is:

$$v(t) = IR(t) \tag{3}$$

where $R(t) = R_o [1 + \alpha\phi(t)]$.

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By combining equations 2 and 3, the result is:

$$v(t) = IR_o \left\{ 1 + \frac{\alpha I^2 R_o}{\gamma'} \left[1 - \exp\left(-\frac{\gamma' t}{C_p} \right) \right] \right\}.$$ (4)

The bridgewire thermal response from equation 4 is represented in figure 1.

The apparent time constant is defined as

$$\tau' = \frac{C_p}{\gamma'}.$$ (5)

This time constant is derived from the current wave form, which is intrinsic to an exponential rise in the bridgewire thermal response. From the above equations and figure 1, useful thermal parameters, which can define thermal behavior of the bridgewire-explosive interface, are derived as follows (refs 2 through 9).

Temperature rise (ϕ) is computed from

$$\phi = \frac{\Delta V}{IR_o \alpha}.$$ (6)

Thermal conductance (γ'), modified heat loss factor due to feedback, from

$$\gamma' = \frac{\alpha I^3 R_o^2}{\Delta v}, \text{ watts/ohm change}.$$ (7)

Heat capacity of the system (C_p) is

$$C_p = \frac{\alpha I^3 R_o^2}{S}, \text{ where } S = \frac{dV}{dt}.$$ (8)

Thermal time constant, (τ') from

$$\tau' = \frac{t'}{0.69} = \frac{C_p}{\gamma'} = \text{time to } 0.63 \text{ (Vmax), seconds}$$ (9)

where t' = time to half voltage, second.

SIMPLIFIED TEST SYSTEM

A simplified thermal transient tester was developed which can be used to control initial current and null out initial resistance of EED. Additional instrumentation included a square wave generator, a digital voltmeter, and two oscilloscopes. One was used to monitor the wave form and the other for recording a digitized wave form. A HP85 desktop computer was used to calculate results from the digital recording and plot data output. The system block diagram is shown in figure 2.

The thermal transient test circuit, which is the heart of the test system, can be easily and economically made, as compared to commercial instrumentation (for example, the Model 605B thermal transient test set, made by Pasedena Scientific Industries). On the other hand, the simplified circuit is slower and requires a skilled operator. Results obtained are the same as those for the more complicated automatic system. Either system is helpful in understanding thermal behavior of bridgewire-explosive interfaces.

The simplified circuit diagram (fig. 3) is basically the same as the standard circuit shown in figure 4. Resistance (R_2) and capacitance (C_2) are eliminated and a separate square wave generator is used. By changing the grounding location, use of a differential amplifier was avoided.

Because it does not have R_2 and C_2 in figure 4, the simplified circuit produces the various types of floating exponential thermal wave forms shown in figure 5. The operator must adjust zero axis and exponential wave forms to set R_1 properly. The exponential wave form can be dropped below the zero axis [fig. 5 (B)] by increasing R_1 and above the zero axis by decreasing R_1, [fig. 5 (A)]. When the values of R_1 and R_0 (EED net resistance) are equal, the exponential wave form starts from zero axis [fig. 5 (C)]. The net positive exponential wave form is proportional to the value of $\Delta R/R_0$ for the electro explosive device and represents the increasing bridgewire temperature. The peak value can be easily found by adjusting the wave form to that shown in figure 5 (D). The following operational steps are used:

1. The electro explosive device is mounted in a shielded test chamber and electronically connected to the shorted test leads.

2. The square wave generator is turned on and set at 10 cps.

3. The test current is adjusted by using the by-pass button and current control knob. It should be noted that 200 mA for high sensitivity EED cannot be used.

4. The exponential wave form is displayed on both oscilloscope screens. Again, it should be noted that the amplitude of the Nicolet digital oscilloscope is 50 times that of the Tektronix 7904 oscilloscope, since its input is taken from the output of the 7A13 amplifier in the Tektronix 7904.

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5. Read hot resistance, equal to (R_1) when the wave form corresponds to figure 5 (D).

6. Reset both oscilloscopes wave forms back to that shown in figure 5 (C).

7. Read offset, zero time, and volts needed to enter data into computer

8. Read the voltage and time when the cursor on the oscillosope is placed on C_1 of the wave-form (fig. 6) to calculate Vmax and stop time, and enter data into computer.

9. Steps 7 and 8 are used for thermal time constant, Δv calculations, and for plotting wave forms. A typical data output is shown in appendix A.

The original wave form was recorded on a Nicolet Explorer III oscilloscope and stored on mini floppy disc. Calculations were made on a HP35 calculator. All calculated data were plotted by a HP 7215A plotter.

DATA ANALYSIS

The data analysis is programmed in BASIC. This program provides calculations of equations 6 through 9, plotting of a smoothed thermal exponential wave form, calculation of τ, and print out by paper or plotter. Basically, there are seven steps in the program.

Step 1. Read input data, which is needed for calculations using the cursor on the oscilloscope - t_o, V_o, I, α, R_1, R_o. Instructions are included in the program.

Step 2. Input data for plotter - X1, X2, X3, Y1, Y2, Y3.

Step 3. Input digital data which is recorded on floppy disc as a function of volts and time (V,t), smooth data, and plot at the same time.

Step 4. Calculate shape of the thermal exponential wave form to define S in equation 8 by moving average method.

Step 5. Calculate Vmax of the thermal exponential wave form to define equations 6 and 7 by mean value determination.

Step 6. Determine thermal time constant by time interpolated for 0.63% of Vmax to define equation 9.

Step 7. Print out all results. Plot of % Vmax versus time, Vmax, I, R_o, α, τ, slope, ϕ, λ. and C_p.

A listing of the HP85 BASIC program is given in appendix B. Sample results for two MK1 squib headers (table A-1) having a 1 mil nichrome bridgewire, before and after loading with borax at 10,000 psi, are shown in appendix A.

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CONCLUSIONS

A simplified thermal transient testing system has been developed and demonstrated for use in measuring the thermal coupling between the bridgewire and the explosive surrounding it in EED. It can be easily used to measure thermal properties and control the quality of loaded EED nondestructively.

REFERENCES

1. L.A. Rosenthal, "Electro-Thermal Equations for Electro Explosive Devices," NAVORD Report 6684, AD 230917, August 1959.

2. L.A. Rosenthal and V.J. Menichelli, "Nondestructive Testing of Insensitive Electro Explosive Devices by Transient Techniques," Materials Evaluation, vol 30, no. 1, pp 13-19, 1975.

3. C.T. Davy, J.F. Heffron, and L.V. Meyers, "Electro Thermal Analytical Response Inspection of Electro Explosive Devices," Contractor Report ARPAD-CR-82001, ARRADCOM, Dover, NJ, March 1982.

4. NASA Technical Briefing, "Simple Nondestructive Tests for Electro Explosive Devices," pp B72-10315, June 1972.

5. A.C. Strasburg, "Data Acquisition System for Transient Pulse Testing," SAND 75-0500, Sandia Labs, Albuquerque, NM, November 1975.

6. L.A. Rosenthal and V.J. Menichelli, "Nondestructive Testing of Insensitive Electro Explosive Devices by Transient Techniques," Technical Report 32-1492, Jet Propulsion Laboratory, Pasadena, CA, July 1970.

7. V.J. Menichelli and L.A. Rosenthal, "Interrelationship of Nondestructive Testing to Fault Determination," Proceedings of the Seventh Symposium on Explosives and Pyrotechnics, Franklin Institute, Philadelphia, PA, 1971.

8. V.J. Menichelli and L.A. Rosenthal, "Fault Determination in Electro Explosive Devices by Nondestructive Techniques," Technical Report 32-1553, Jet Propulsion Laboratory, Pasadena, CA, July 1972.

9. L.A. Rosenthal, "Thermal Response of Bridgewires Used in Electro Explosive Devices," Rev Sci Instr, vol 32, pp 1033-1036, September 1961.
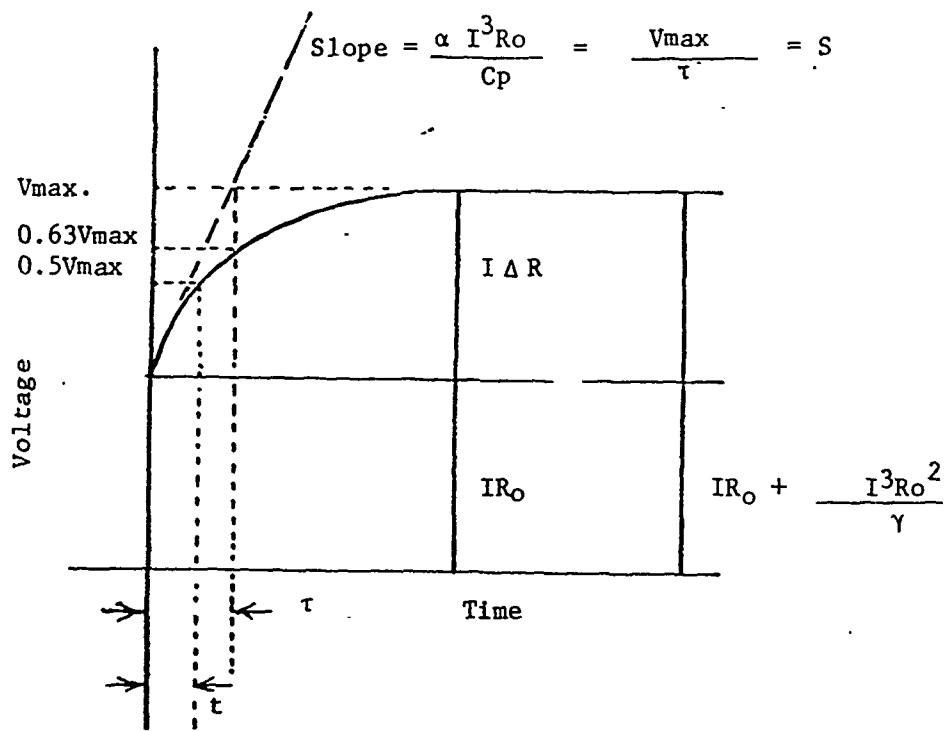
Figure 1. Thermal response curve

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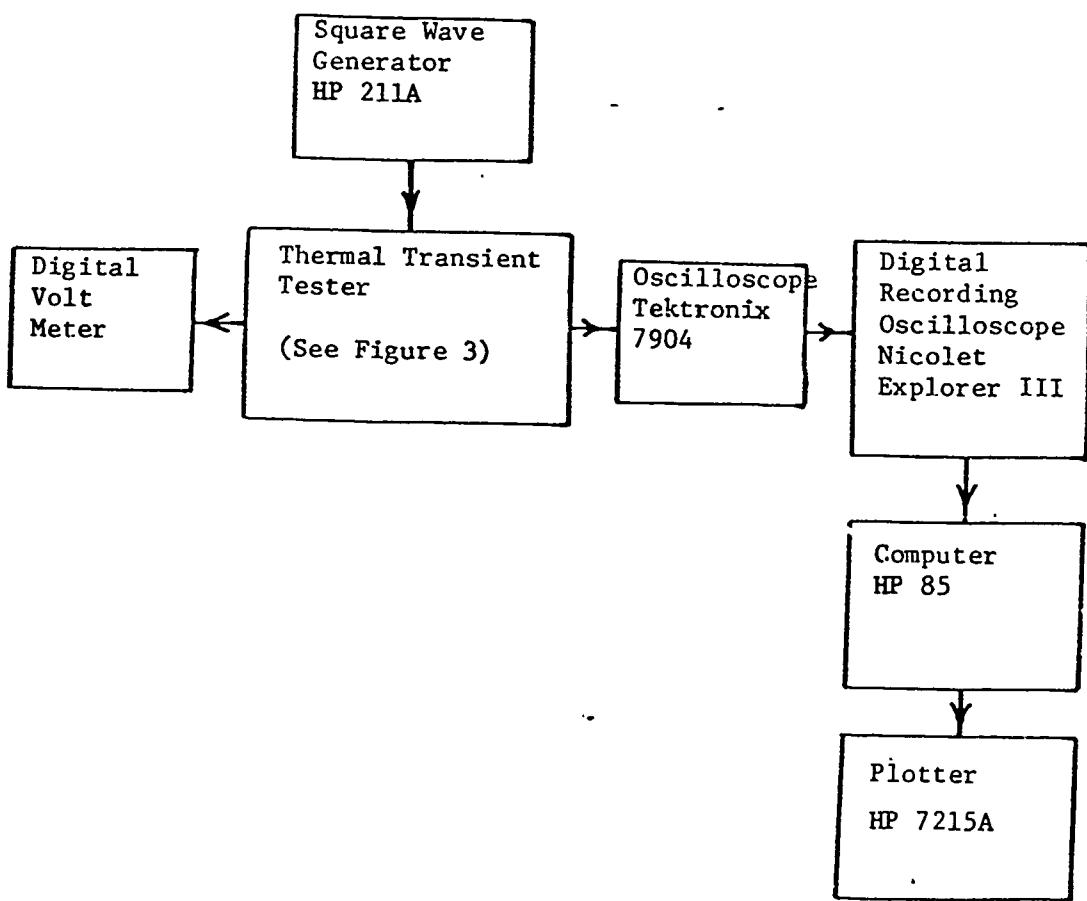
Figure 2. Block diagram of thermal transient test instrumentation

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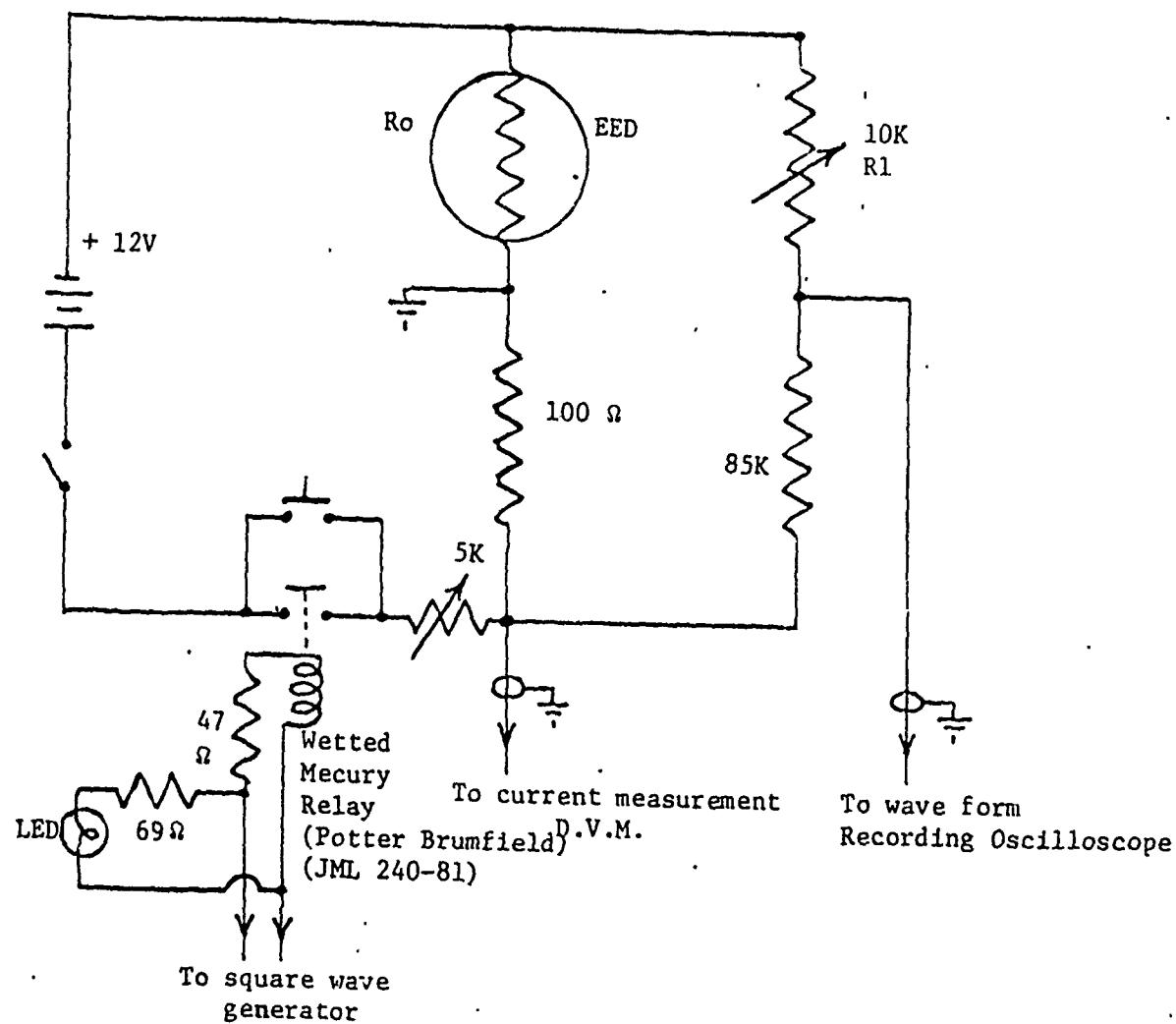
Figure 3. Simplified thermal transient test circuit

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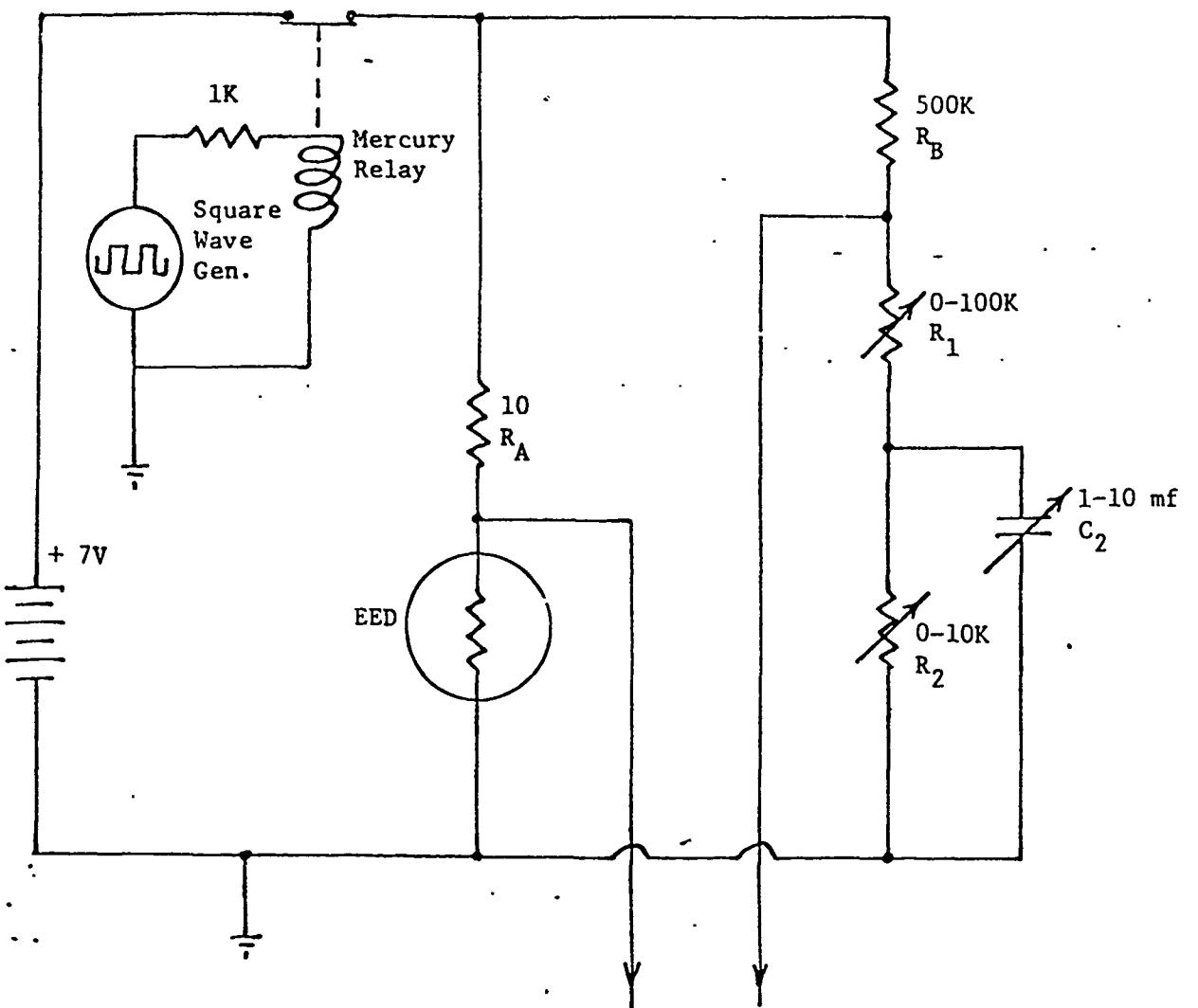
Figure 4. Typical thermal transient test circuit
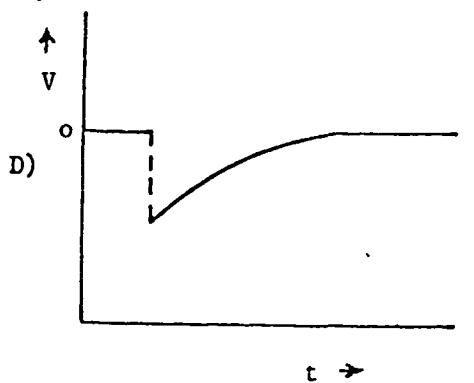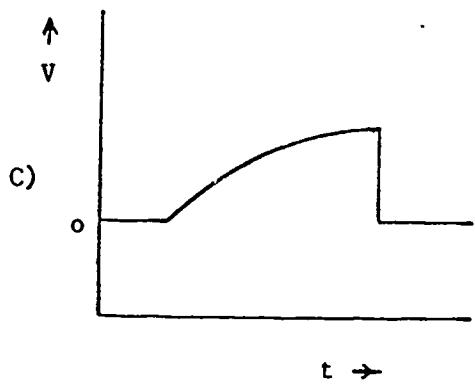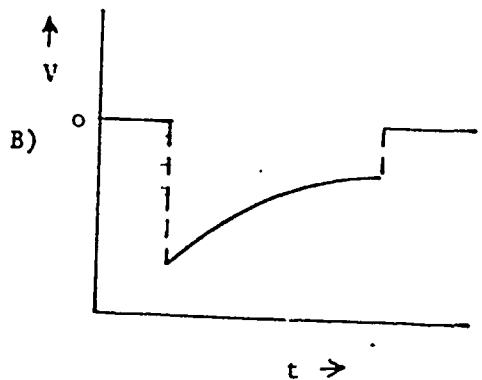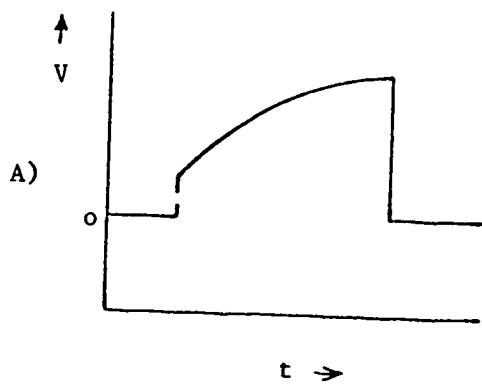
Figure 5. Typical types of wave forms

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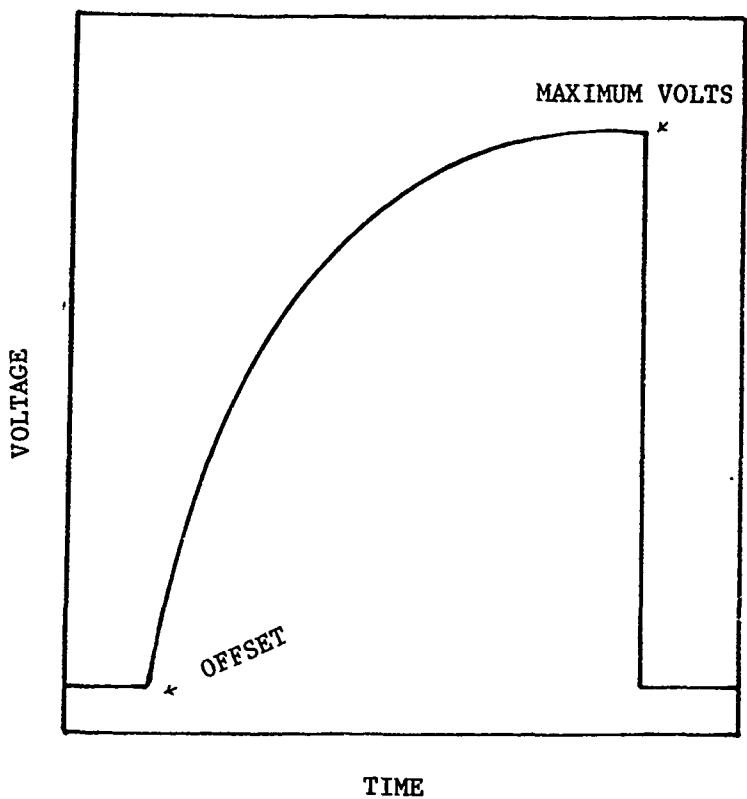
Figure 6. Cursor points on oscilloscope trace to calculate results

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APPENDIX A

TYPICAL RESULTS ON MK1 SQUIBS

Table A-1. MK1 squib data summary

Condition	Squib	Initial resistance (ohms) R_o	Test current (amp) I_o	Thermal time constant (millisec) T	Maximum voltage rise (millivolts) V_m	Slope $\frac{V_m}{T}$	Thermal conductance[a] γ'	Heat capacity[b] C_p	Temp rise (°C) ϕ
Unloaded	1	2.63	0.08	8.216	8.16	0.9932	5.64	4.63	298.0
Loaded[c]	1	2.48	0.08	5.483	4.40	0.8025	9.30	5.11	171.0
Unloaded	2	2.065	0.08	6.517	2.62	0.4020	10.8	7.06	122.0
Loaded[c]	2	2.07	0.08	5.646	1.664	0.2947	17.1	9.69	77.3

Nichrome Properties
_____

Temperature coefficient of resistance = 0.00015 hard, 0.00013 annealed
Melting point = 1400°C
Density = 9.25 g/cm³
Resistivity, ohms/circular mil/ft at 0°C = 630 hard, 675 annealed
Bridgewire, 0.001 in. diameter, 0.060 in. long
Composition: 61% Ni, 15% Cr, and 24% Fe

_____

[a] Watt/°C x 10⁵

[b] Watt-sec/°C x 10⁷

[c] Loading was done with borax at 10,000 psi
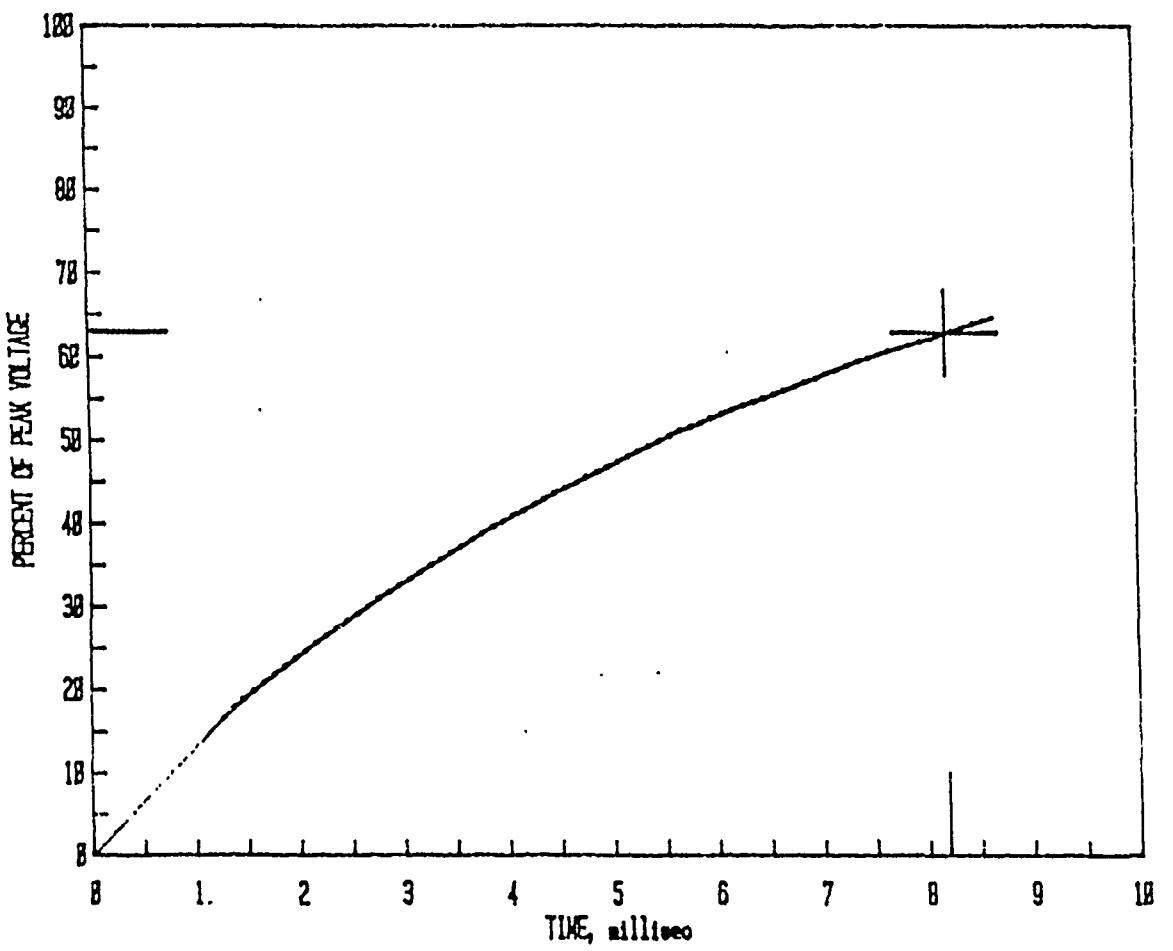
TEST #1, PEAK VOLTAGE = 8.16 millivolts

Figure A-1. Test number 1 on MK1 squibs, unloaded

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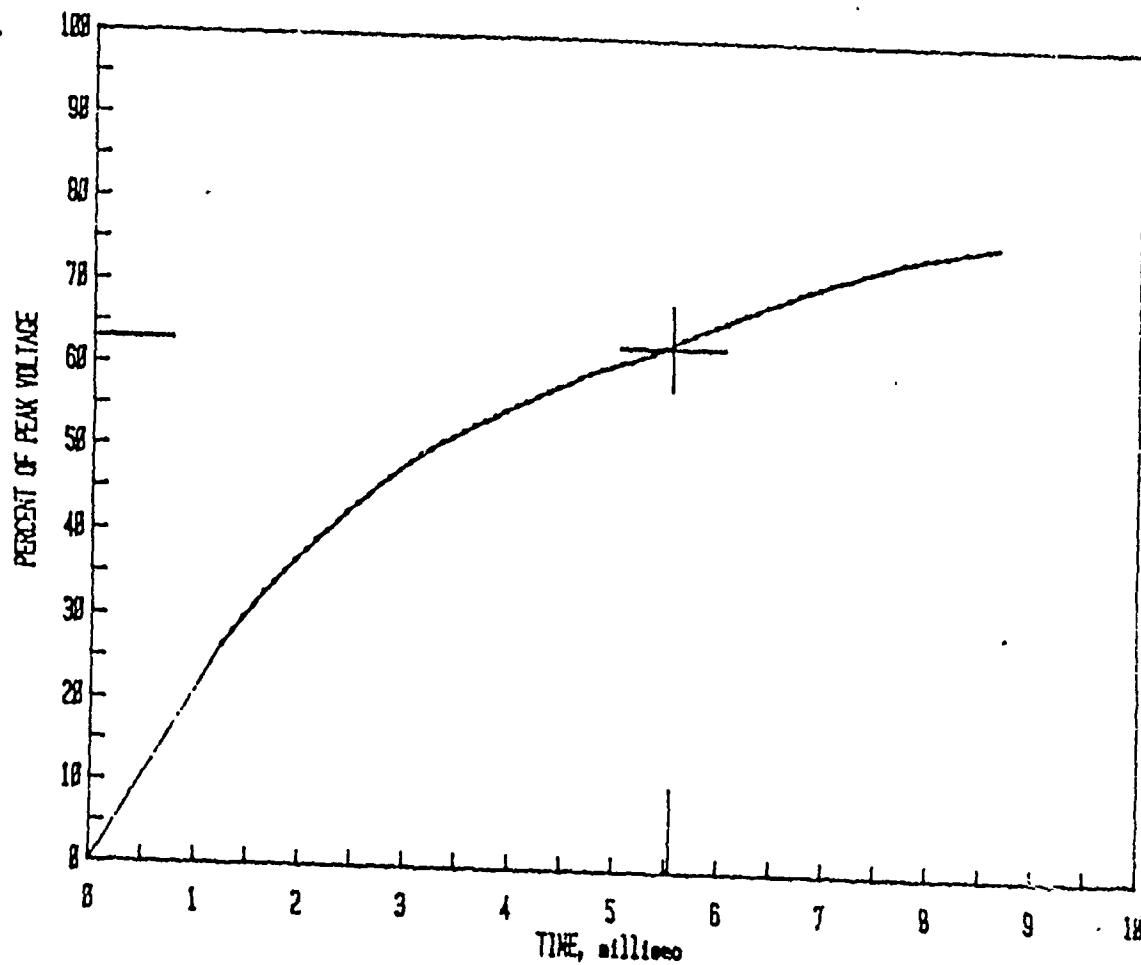
TEST #2, PEAK VOLTAGE = 4.40 millivolts

Figure A-2. Test number 2 on MK1 squibs, loaded with borax
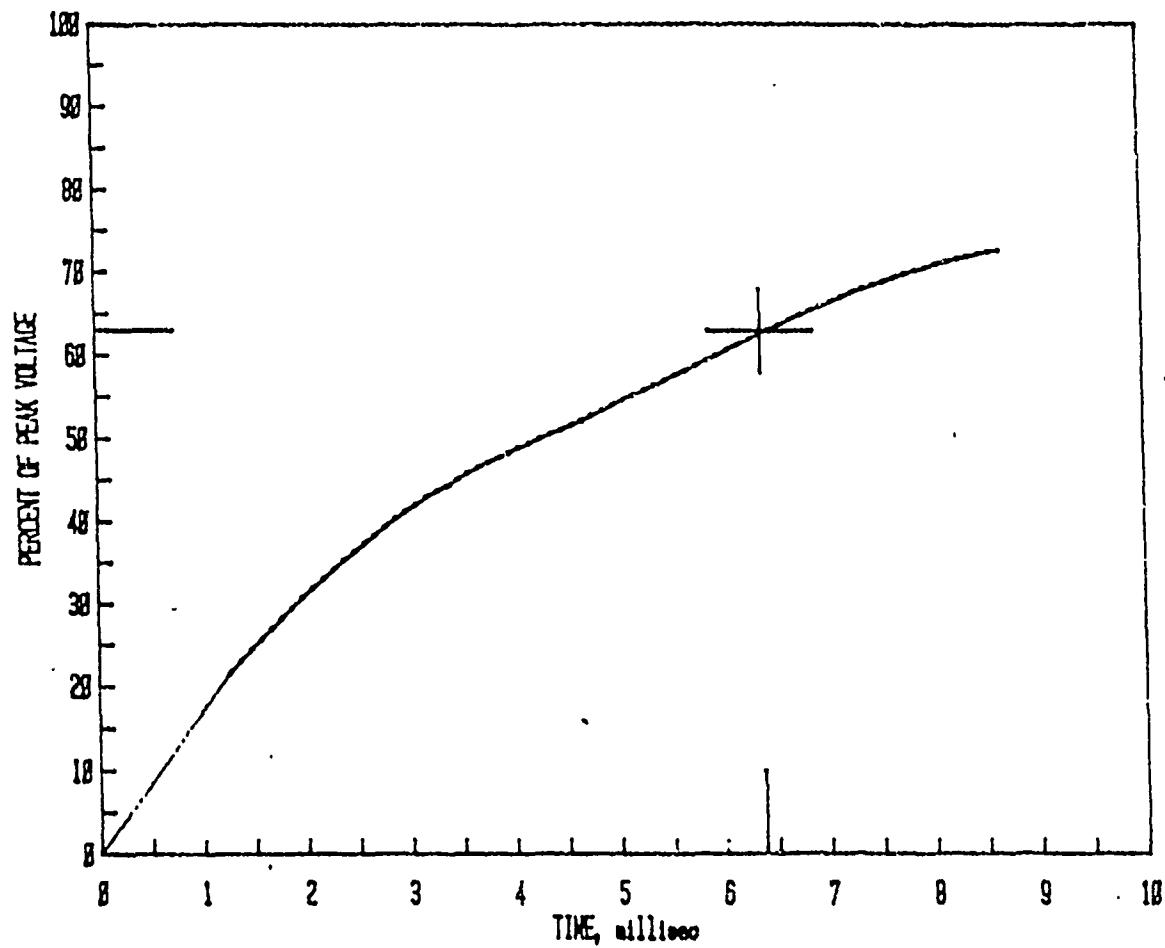
TEST #3, PEAK VOLTAGE = 2. 62 millivolts

Figure A-3. Test number 3 on MK1 squibs, unloaded

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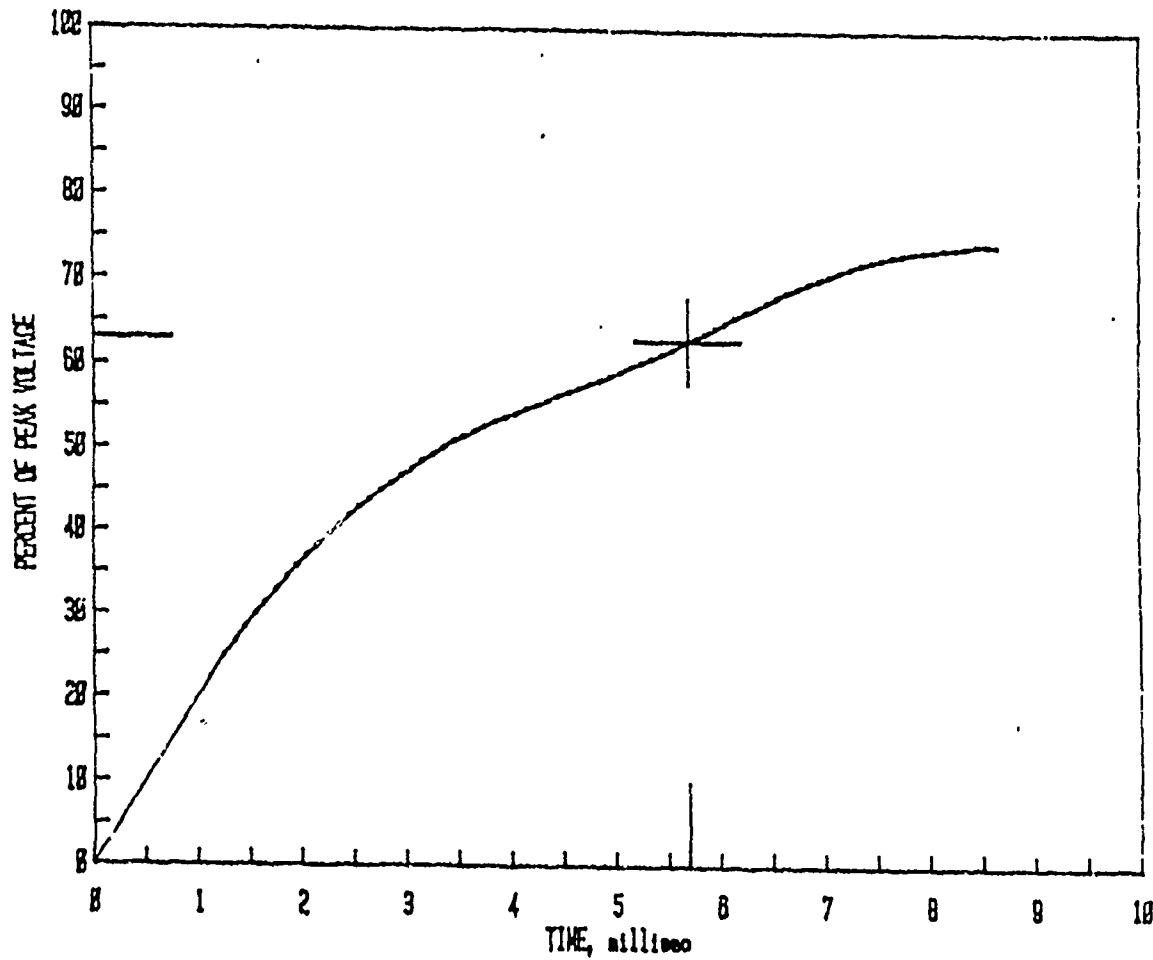
TEST #4, PEAK VOLTAGE = 1.664 millivolte

Figure A-4. Test number 4 on MK1 squibs, loaded with borax

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APPENDIX B

BASIC PROGRAM FOR THERMAL TRANSIENT TEST

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```
10 REM    CODE "K3WIRE"            570 C'IZE 3,.35
20 DISP "ENTER SAMPLE ID"          580 LABEL USING "K" ; S$
30 INPUT I$                        590 AXES X3/2,Y3,X1,Y1
40 PRINT "        ";I$             600 CSIZE 3,.35
50 PRINT                           610 FOR X=X1 TO X2 STEP X3
60 PLOTTER IS 705                  620 MOVE X,Y1
70 LOCATE 30,110,20,80             630 SETGU
80 DIM X$[80],Y$[80],T$[80],S$[    640 IPLOT 0,-2,-2
   180]                            650 SETUU
90 DISP                            660 LABEL USING "K" ; X
100 DISP "ENTER START OF X AXIS"   670 NEXT X
110 INPUT C1                       680 MOVE X1+(X2-X1)/2,Y1
120 DISP                           690 SETGU
130 DISP                           700 IPLOT 0,-6,-2
140 DISP "ENTER END OF X AXIS"     710 LORG 4
150 INPUT C2                       720 LABEL USING "K" ; X$
160 DISP                           730 SETUU
170 DISP                           740 LORG 8
180 DISP "ENTER TIC MARKS FOR X    750 FOR Y=Y1 TO Y2 STEP 2*Y3
    AXIS"                          760 MOVE X1,Y
190 INPUT C3                       770 LABEL USING "K" ; Y;" "
200 DISP                           780 NEXT Y
210 DISP                           790 MOVE X1,Y1+(Y2-Y1)/2
220 DISP "ENTER START OF Y AXIS"   800 SETGU
230 INPUT C4                       810 IPLOT -6,0,-2
240 DISP                           820 SETUU
250 DISP                           830 DEG
260 DISP "ENTER END OF Y AXIS"     840 LDIR 90
270 INPUT C5                       850 LORG 6
280 DISP                           860 LABEL USING "K" ; Y$
290 DISP                           870 LDIR 0
300 DISP "ENTER TIC MARKS FOR Y    880 DISP "ENTER OFFSET VOLTAGE (
    AXIS"                              millivolt)"
310 INPUT C6                       890 INPUT G
320 X1=C1                          900 DISP " ZERO TIME OFFSET (mil
330 X2=C2                              lisec)"
340 X3=C3                          910 INPUT O
350 Y1=C4                          920 DISP " ENTER MAX VOLTS IN mi
360 Y2=C5                              llivolts"
370 Y3=C6                          930 DISP "UNCORRECTED VALUE"
380 SCALE X1,X2,Y1,Y2              940 INPUT M1
390 T$="TEST #3, PEAK VOLTAGE =    950 DISP "ENTER CURRENT (amperes
    2.62 millivolts"                   )"
400 S$=""                          960 INPUT I0
410 X$="TIME, millisec"            970 DISP "ENTER COLD RESISTANCE"
420 Y$="PERCENT OF PEAK VOLTAGE"   980 INPUT R0
430 FRAME                          990 DISP " ENTER TEMP. COEFF. OF
440 FRAME                              RESISTANCE"
450 FRAME                          1000 INPUT R1
460 MOVE X1+(X2-X1)/2,Y2           1010 A1=0*40+1
470 SETGU                          1020 A0=A1
480 IPLOT 0,-70,-2                 1030 A2=A1+101
490 SETUU                          1040 A3=1
500 LORG 6                         1050 A5=4
510 CSIZE 4,.5                     1060 DIM B$[280],A$[8200]
520 LABEL USING "K" ; T$           1070 OUTPUT 702 ;"N0"
530 MOVE X1+(X2-X1)/2,Y2           1080 IOBUFFER B$
540 SETGU                          1090 TRANSFER 701 TO B$ FHS ; CO
550 IPLOT 0,2,-2                        UNT 230
560 SETUU                          1100 CLEAR 7
```

```
1110 V0=VAL(B$[5,8])                    1690 PRINT "HEAT CAPACITY =";C
1120 H0=VAL(B$[10,13])                  1700 GOTO 1740
1130 V1=VAL(B$[14,20])                  1710 T1=(Y6-63)/(Y6-Y7)*(X6-X7)+
1140 H1=VAL(B$[21,27])                       X7
1150 OUTPUT 702 ;"D3D2"                  1720 F=1
1160 IOBUFFER A$                         1730 GOTO 1200
1170 TRANSFER 701 TO A$ FHS ; CO         1740 FOR Z=0 TO .75 STEP .05
     UNT 8192                            1750 L=63
1180 CLEAR 7                             1760 PLOT Z,L
1190 F=0                                 1770 NEXT Z
1200 X5=0                                1780 PENUP
1210 Y5=0                                1790 FOR Z=T1-.5 TO T1+.5 STEP .
1220 N=0                                      05
1230 FOR I=A1 TO A2 STEP 2*A3            1800 L=63
1240 P=256*NUM(A$[I])+NUM(A$[I+1         1810 PLOT Z,L
     ])-65536*(NUM(A$[I])>=128)          1820 NEXT Z
1250 J=I/2-.5                            1830 PENUP
1260 V=P*V1                              1840 FOR L=0 TO 10 STEP .1
1270 V=V-G/1000                          1850 Z=T1
1280 V=V*1000                            1860 PLOT Z,L
1290 T=(J-H0)*H1                         1870 NEXT L
1300 T=T*1000                            1880 PENUP
1310 T=T-O                               1890 FOR L=58 TO 68 STEP .1
1320 X4=T                                1900 Z=T1
1330 Y4=V*100/M1                         1910 PLOT Z,L
1340 X4=X4+X5                            1920 NEXT L
1350 X5=X4                               1930 PENUP
1360 Y4=Y4+Y5                            1940 END
1370 Y5=Y4
1380 N=N+1
1390 NEXT I
1400 PLOT X6,Y6
1410 X6=X4/N
1420 Y6=Y4/N
1430 PLOT X6,Y6
1440 PENUP
1450 Y6=Y6+.005
1460 Y6=INT(Y6*100)/100
1470 DISP Y6,X6
1480 IF F=1 THEN 1500
1490 IF Y6>63 THEN 1710
1500 A1=A1+A5
1510 A2=A2+A5
1520 Y7=Y6
1530 X7=X6
1540 IF A2<A0+40*10 THEN 1200
1550 M1=M1*.02/1000
1560 S=M1/T1
1570 T2=M1/(I0*R0*R1)
1580 C=R1*I0^3*R0^2/S
1590 C1=R1*R0^2*I0^3/M1
1600 PRINT "VOLT (max) =";M1
1610 PRINT "CURRENT(amps) =";I0
1620 PRINT "R (ohms) =";R0
1630 PRINT "COEFF of RES =";R1
1640 PRINT
1650 PRINT "TIME CONST =";T1
1660 PRINT "SLOPE(Vmax/t)=";S
1670 PRINT "TEMP RISE(C) =";T2
1680 PRINT "HEAT LOSS =";C1
```

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